Visualizing International Deforestation Trajectories Using ArcGIS

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Abstract

With the increase in permanent forest clearing, global deforestation is having a major impact on our finite resources. A growing public awareness of current forestry practices around the world is provoking people to question the management of these valuable forested regions. We will present a conceptual model that links visualizations and quantitative data to spatial locations over a range of time periods. This information will enable people from around the world to freely explore the forces behind deforestation at both regional and local levels. Using ArcGIS we generate information vignettes that visualize spatial and temporal data from a variety of vantage points to provide increased communication between the international public and parties directly involved in permanent forest clearing.

Keywords: geographical information systems, global deforestation, image classification, land use planning, modeling, remote sensing

Introduction

Global deforestation is having a major impact on our world's finite resources. Deforestation is a catalyst for negative change that includes global warming from CO_2 emissions (Fearnside, 2000), soil degradation (McGrath et. al., 2001) and long-term reduction in plant biodiversity (Mcintyre et. al., 2003). Some causes of deforestation, including urban sprawl (Mitchell, 2001), tobacco (Geist, 1999) and soybean cultivation (Dros, 2004), are exacerbated by a lack of comprehensive policy governing land use in affected areas (Suzuki, 2001). An extensive study conducted in South America by Geist and Lambin (2002) explains some of the proximate and underlying causes of tropical deforestation, such as agricultural expansion, infrastructure extension, and wood extraction. According to the Global Forest Resources Assessment 2000 from the Food and Agriculture Organization of the United Nations, there was a net loss of 9.4% of the world's forests due to deforestation from 1995 - 2000 (Forest Resource Assessment, 2000).

A network of conservation groups around the world have focused on slowing deforestation by promoting sustainability and educating the public about underlying causes driving deforestation. For example, the Rainforest Alliance and David Suzuki Foundation disseminate knowledge to the general public, making the environmental impacts of worldwide forestry activities more transparent. A variety of tools have been implemented to effectively deliver this valuable information: web-based publications, brochures, emails, and regional forums have proven to be helpful tools in the battle against widespread deforestation. This information produces a growing public awareness and provokes people to question the management of global forested regions.

Pictures of land use changes can also be quite effective in this role. Remotely sensed imagery can be assembled from multiple sources. An example of this is LandSAT multi band imagery, which is available in archives dating back to 1972. Information extracted from these images can be used to clearly identify historical changes in land use. Alves (1999) used LandSAT images to measure deforestation in a region within western Brazil, detecting a 35.5% reduction in forest cover in the area between 1972 and 1995. Objective and statistically based observations such as this portray land use changes in a manner easily understood by the general public.

The "Catch 22" for conservation groups is that whilst remote sensing imagery is very powerful, it cannot be used to document or predict future deforestation events before they occur. However, recent developments in visualization technology do allow computers to create near-photorealistic visualizations, derived from models, which depict land use changes before they occur. Today's model-driven visualizations have become quite realistic, increasing their representational validity of real world vistas (Daniel and Meitner, 2001). To use models that address social implications of site-specific forest management actions, it is arguably necessary that the rendered visualizations be realistic landscapes (Sheppard, 2000). This paper presents a method that combines the power of remotely sensed imagery and computer visualization, providing conservation groups and regulating agencies with a tool to simulate the future and communicate important impacts before they occur.

Developing Visualizations

Members from the University of British Columbia's, Collaboration for Advanced Landscape Planning have been developing tools to make the simulation process both easier and more realistic. The computer technology required to realistically simulate deforestation is complex. Development of a few helpful tools, have made this technology more manageable and more widely available. There are countless ways in which one can go about developing these simulations but it would be outside the scope of this paper to detail each of them. Rather, our goal is to present one method that we feel is quite relevant to the rapid visual depiction of global deforestation. To explain this method we have highlighted some basics of image classification, clear cut modeling, and the final rendering process. The major advantage of the conceptual model specified in this article is that it provides a method for the creation of near-photorealistic renderings based on classified remotely sensed data. To implement the model, five major steps are needed; data collection, image classification, digitization, digital manipulation and rendering.

This paper presents a method that combines the power of remotely sensed imagery and computer visualization. Visualization can be used to depict both visual and non-visual information. For the purposes of this paper, realistic visualization refers only to the accurate reproduction of the visual variation present in a forested area. Remote sensing sensors that are sensitive to the visible spectrum can capture this variation in much the same way that a digital camera can be used to capture an aerial picture of a forest. The captured information is stored in the Red, Green and Blue information "bands" of a satellite image. The variation in the data from these sensors can be quickly classified by modern computers to provide a basic understanding of the forest cover and surrounding land uses such as roads and lakes.

The first step in developing our simulation of a real forested environment was the collection of the required data. At a bare minimum, the data needed to produce a visualization of a forest, consists of topography and forest cover data. Topographic information is often available as contours, mass points or pre configured digital elevation models. Forest cover data is less readily available. In most cases, forest cover data is compiled using a combination of stand level survey, aerial photo interpretation and automated classification of remotely sensed imagery.

The second step in our conceptual model was the production of a classification scheme. This process entails a simple and generalized classification of the visible variation that can be seen on an aerial photograph. PCI Geomatica was used to classify the Red, Green and Blue (visible spectrum) bands by clustering pixels with similar brightness values into groups. This classification provides a rapid differentiation and delineation of areas that are visibly different, which is an excellent basis for the creation of landscape visualizations. One example of a similar procedure using remotely sensed data is hyperspectral imagery, which has been successfully used to identify the five different species types in the Harvard Forest (Martin et. al., 1998). A further example is neural networks, such as ARTMAP which have been used to increase the overall predictive accuracy of species from a remotely sensed image (Carpenter et. al., 1997). The fusion of two or more types of imagery can provide more accurate classification of forest cover in many regions of the world (St. Onge et. al, 2004; Coops et. al., 2004). The visibly different forest categories can then be cross-referenced with a site-index (a ground control), which provides a precise indicator of the forest cover species.

To illustrate the classification process, an orthophoto was categorized into six classes. The original orthophoto used in this study is shown in Figure 1. The automatically (or unsupervised) classified image, with its six forest cover classes is shown in Figure 2.

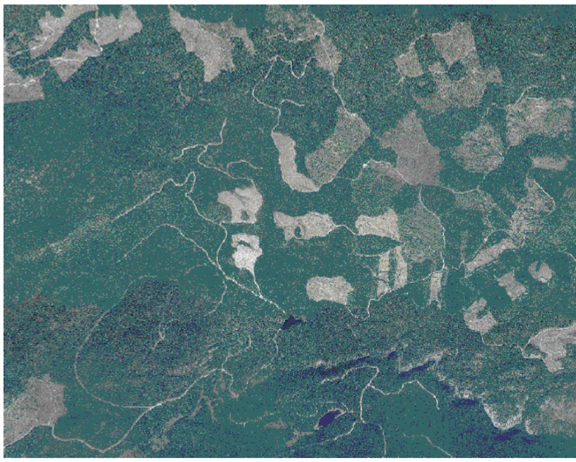

Figure 1: The original orthophoto

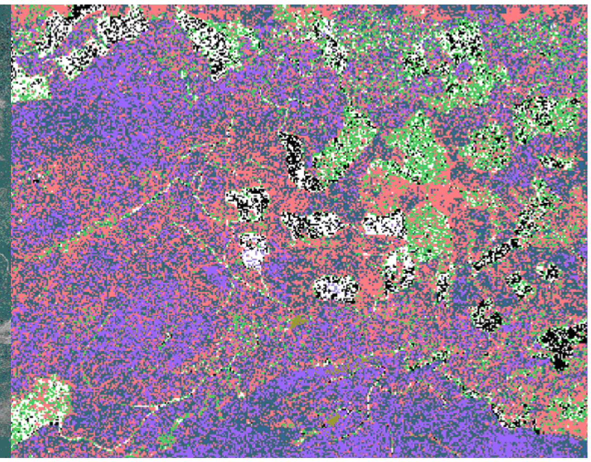

Figure 2: The classified image

One of the forest classes shown in Figure 2 represents existing clear cuts. Understanding the impacts that existing deforestation has caused requires that this classification be compared to a "clean slate", or pristine forest. When available, satellite imagery that predates the clear cutting can be used. In cases when this information is not available, the rubber stamp tool in Adobe Photoshop can be used to "restore" the original forest cover by filling in the clear cuts based on the forest present in the immediate surroundings of these cuts. Figure 3 illustrates how this procedure has been used to "erase" existing deforestation, visually restoring the original pristine forest and providing a clean slate from which to test different future forest outcomes.

The third step in our conceptual model involved the creation of the alternative management outcomes discussed above. Nine distinct forest management scenarios were generated in this conceptual model, varying along two dimensions: quantity of forest harvested and the degree to which visual stewardship principles were applied. Each dimension consisted of three levels resulting in a 3x3 matrix of possible scenarios shown in Table 1.

Table 1: Matrix of scenarios to be visualized

		Amount of Forest Harvesting		
		Low	Medium	High
Degree of Visual Stewardship	Low	S_1	S_2	S_{base}
	Medium	S_4	S_5	S_6
	High	S_7	S_8	S_9

The existing clear cuts depicted on the satellite image in Figure 1 represented large amounts of harvesting and a low degree of visual stewardship. This scenario was deemed the base case (labeled S_{base} in Table 1). The "Amount of Forest Harvesting" dimension was varied by reducing the number of cut blocks, and the "Degree of Visual Stewardship" dimension was changed by altering the shape of the cut blocks, feathering the edges and introducing riparian buffers and patch retention. Each column of scenarios in Table 1 harvests precisely the same volume of wood.

The fourth step for our conceptual model entailed the definition and digitizing of the intended clear cuts based on the nine scenarios. These clear cuts were captured as polygon vectors, which were then overlaid (implemented) onto the pristine forest cover shown in Figure 3. The base scenario (S_{base} in Table 1) was digitally converted from the image in Figure 1. Figure 4 shows a partially completed digitizing process. The remaining 8 scenarios were "designed" using S_{base} as the starting point.

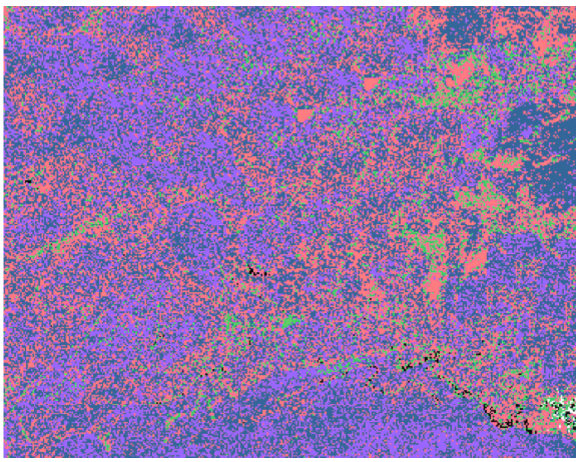

Figure 3:Hypothetical pristine classification

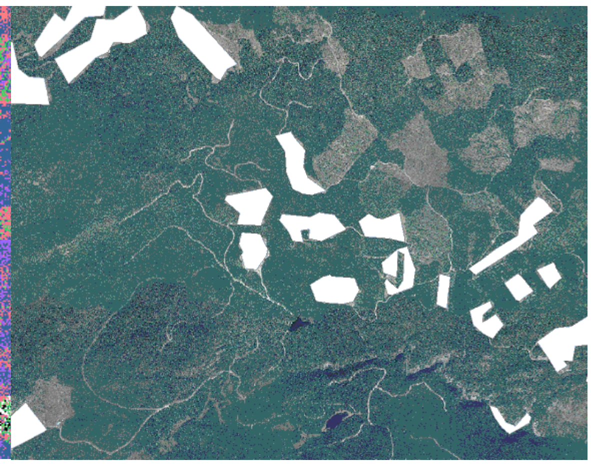

Figure 4: Digitizing the original clear cuts

The underlying polygonal data of the base scenario was altered according to specified design parameters. For example, scenario nine (S_9 - high visual stewardship and high forest harvesting) was created by transforming the rectilinear harvest blocks in the base case into more organic shaped polygons with interior retention patches and feathered edges around the periphery of each block. In order to achieve these changes, several steps were required.

ArcGIS provided some key tools used to "design" the 8 new scenarios. First, the polygons were manually smoothed using digitizing and geo-processing tools. The medium and high visual stewardship scenarios required edge feathering. Feathering is a procedure which introduces a transition zone, gradually increasing the cut intensity towards the centre of the block.

Since feathering alters the density of harvest, and each column of scenarios in Table 1 required equal volume extraction, the polygon boundaries needed to be revised to accommodate this change. The buffer tool was used to calculate and create a revised exterior edge for each block. This revised boundary was iteratively refined. ArcGIS Model Builder was used to automate this iteration process.

As an example, the ArcGIS Model Builder model used in S_9 required four shape files as input: the original cut blocks, the manually generated feathered edges for each of the cut blocks, internal retention patch polygons and rivers/streams (used to create riparian buffers). Model Builder was used to run a 62 step process that automatically selected and created riparian buffers, altering the size of the feathered areas around each cut block and retention patch. The model output a single shape file (Figure 9) and a set of area and volume statistics which were iteratively matched with the original design parameters.

For clarification purposes, Figures 5 illustrates the original orthophoto. Figure 6 shows the S_{base} scenario, which is the original digitized cutblock shape. Figure 7 shows the S_6 scenario, and Figure 8 shows the S_9 scenario.

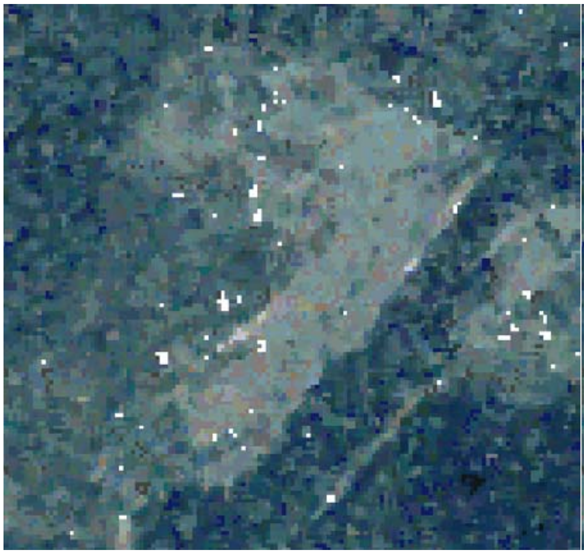

Figure 5: Original orthophoto

Figure 6: Low visual stewardship output

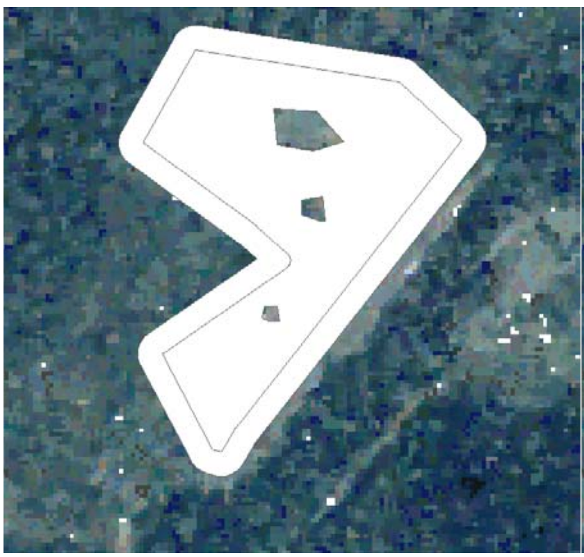

Figure 7: Medium visual stewardship output

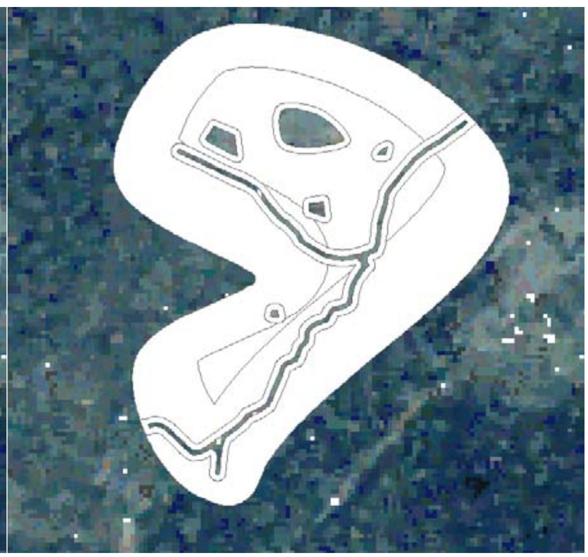

Figure 8: High visual stewardship output

The polygon boundaries in Figures 6-8 represent “isolines” of forest density in much the same way that contours represent “isolines of constant elevation”. The density contours in Figures 6-8 were converted to an 8 bit raster density surface using ArcGIS. For more detail on the process of using grayscale images in visualizing complex forestry operations see Meitner and Gandy (2005).

After the raster creation, the harvesting density surface was then inserted into Visual Nature Studio (VNS) together with topographic data (from step 1) and the PCI Geomatica forest classification shown in Figure 3. Visual Nature Studio (software created by 3D Nature), was used to create six ecosystems based on the PCI Geomatica classification classes. These ecosystems were spatially defined by linking them to the image shown in Figure 3. VNS was then used to create a software camera, lighting atmospheric and water effects. The simulation was then rendered, producing the image shown in Figure 9.

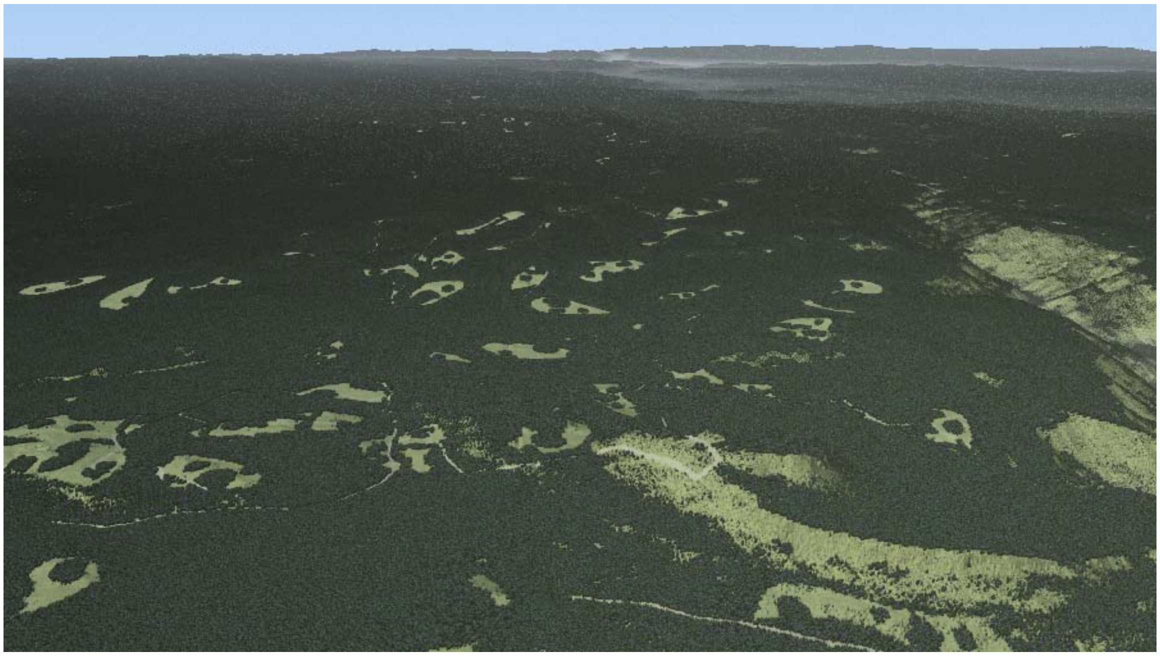

Figure 9: Test rendering of scenario nine

Adapting the conceptual model

The primary purpose for developing the conceptual model was to provide conservation and sustainability organizations with a powerful communications tool capable of delivering images that show how human impacts effect global deforestation. The model we have developed makes these impacts independent of time, allowing for accurate simulation of future changes. The five step conceptual model in this paper provides an easily used method that can be applied to rapidly visualize local and regional deforestation. The rapid creation of photo-realistic depictions can be scientifically backed by the raw data used to create them, allowing them to become powerful tools for use in the advocacy of real environmental concerns in an objective, scientific and non-emotional way.

There are numerous reasons why this method has the potential to be very influential with mainstream conservation organizations. One reason previously discussed, highlights how simulations can use historical and hypothetical data to generate realistic visualizations of possible trajectories of the future. Drawing from proposed plans and policies for a particular region, conservation groups can swiftly generate imagery of what may happen if the plans were implemented. In addition, including imagery in the decision-making process may cause a shift in the way policymakers, as well as private and public land owners understand how their decisions affect the landscape. The imagery can also effectively communicate these proposals to the general public, something not easily achieved through traditional means. As a result, this tool can provide additional transparency to the decision-making process, possibly resulting in a solution more favorable to the sustainability of the region.

The application of 3D visualizations to sustainable management appears promising in communicating complex scientific relationships. The potential is increasingly being recognized, as evidenced by the emerging tools for creating data-driven visualizations of environmental states (Meitner, Gandy & Sheppard, 2005). Our hope is that translating numeric representations of future forest conditions into more salient visual representations will help engage the public in a richer, clearer discourse with scientists about possible outcomes resulting from a variety of decisions. Ultimately, this may lead to more inclusive and informed participation in the decision-making process affecting natural resources.

Conclusions

The ability to manipulate the past and create possible trajectories of the future, without having to implement these change in the real world, provides a powerful communications tool that conservation groups can apply to their endeavors. Advances in realism of these computer simulations (Meitner et al, in press), in conjunction with recent progress in real-time, near-photo realistic rendering (Cavens, 2002), offer the promise of even greater simplicity for end-users to interact with these systems. This could potentially produce a more accurate emotional response due to increased realism, and facilitate a greater degree of spatial understanding of the underlying data due to the increased interactivity they afford (Lum et al., 2002). Adding further components of realism, increasing the accuracy of classification and producing more intelligent automated tools will streamline the process by which we create visions of the future. This method offers an exciting new way to approach solutions to land use management problems in the world’s forested regions.

The five steps of the conceptual model presented in this paper, can be applied to a wide range of problems facing the sustainability of natural resources, particularly deforestation. Simulations, using trajectories derived from raw data of future deforestation in a region, can be easily generated for a number of real and hypothetical scenarios. The visualizations can then be distributed to the public via websites, brochures and a variety of other methods used by conservation groups to inform the public. This information will enable people around the world to freely explore new information that shows how human impacts affect global deforestation. Visualizations provide information in a format that is easily comprehensible by the general public. Perhaps this will provoke an even greater number of people to affect positive change toward conserving our finite natural resources.

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